Details of the method, as well as numerous examples from biology, genetics, physics and agriculture will be given in two subsequent papers.

¹ Actually it was found that the chances are 20000 : 1 that a molecule of oxygen gas would have a resultant velocity, at 0° C., of less than 50 meters per second, or greater than 2500 meters per second, the mean being 353.6 meters per second. Here the mean is not the arithmetical mean of the variables, but the nth root of the products of the n (dependent) variables. The theoretical basis for this will be given in another paper. For a mathematical discussion see Galton and McAlister, *Proc. Roy. Soc. Lond.*, **29**, 1879 (365).

A CRITICAL STUDY OF FERTILIZER EXPERIMENTS

By C. B. Lipman and G. A. Linhart

University of California

Communicated by W. J. V. Osterhout, June 1, 1920

Among the most expensive and time-consuming experiments in agricultural investigations have been those which attempt to ascertain the proper chemical amendments or fertilizers for soils. This applies in particular to the long-term fertilizer experiments like those at Rothamsted in England, at State College in Pennsylvania, and at Wooster and Strongsville in Ohio. Conceived and inaugurated, as they were, at times when little or no real authentic information was available relative to the nature of soils and plants, it is but natural that fallacious and short-sighted planning should have dominated them. It occurred to one of us that as critical thinking in this field has become more general, and facts more plentiful, it is high time that fertilizer experiments in general and the "long-term" experiments in particular be subjected to critical scrutiny. It seemed desirable to employ the statistical method for this purpose, particularly in view of the striking results obtained in this laboratory by our former associate, D. D. Waynick. It seemed clear to one of us that if, as Waynick, and Waynick and Sharp had demonstrated, the variability of soils and of plants is very large even within selected and presumably uniform material, one could not expect previous fertilizer experiments to be of much value, since the factor of variability has been entirely ignored in their arrangement and study, and the probable error to which they were subject was not determined. Accordingly, Lipman and Waynick began in January, 1919, a systematic study by statistical methods of the results of fertilizer experiments at the Ohio and at the Pennsylvania Agricultural Experiment Stations. Mr. Waynick left this laboratory the following July, but with a number of interruptions, the work has been continued, and we hope to issue the voluminous data, together with a critical discussion of them, in due course. Since the work may be a long time in the press, we deem it wise to present here a few of the salient and most im-

portant findings of our studies, so that our colleagues may be apprised of what we consider to be an investigation of a fundamental nature, not merely on account of the importance of the subject itself, but because of its important bearings on agricultural research.

It seems that the originators of both the Ohio and the Pennsylvania experiments saw the value of replicating check plots, while not recognizing the value of such replication for the treated plots. Only in the case of two complete fertilizer plots in the Ohio experiments, was the fertilizer treatment the same. In all the others every treatment was different from that of every other. This situation renders it difficult to subject their data to statistical treatment in the most desirable way. Fortunately, however, the long series of years during which the plots were studied gives, in a certain sense, a replication of plots of each kind. Our procedure has been, therefore, to group the plots in different ways including the following:

1. All the check plots for each year.
2. One check plot for all the years.
3. All the plots treated with "one-element" fertilizers in one year.
4. Every "one-element" fertilizer plot for all the years.
5. The same double study for the "two-element fertilizer plots."
6. The same for the "three-element" fertilizer plots.

In addition to these groupings, others were made in which a given plot was studied with each crop in the rotation, so as to allow of only three to eight "yield" data for each plot. It may be said in passing that the rotation study included in these experiments only serves to complicate a situation which was already sufficiently difficult. We shall show in detail in the complete study which is to be published, that these experiments are utterly inadequate for solution of the questions involved and that all such fertilizer experiments are so fallacious as that they do not justify the use of the large amounts of money that are constantly being lavished upon them.

For the sake of brevity, only a few of our findings, from the study of the Ohio data alone, are summarized here.

1. The "one-element" fertilizer treatments show no significant increases in yield over the yields obtained on the untreated check plots. All statements to the contrary which have heretofore been made are erroneous and the data on which they are based were obtained by a misleading method of procedure and evaluation.

2. The "two-element" fertilizer plots give definite increases in yield over the untreated control plots. Whether or not the increases are profit-yielding, however, is a question which will be discussed later.

3. The "three-element" fertilizer plots give definite increases in yield over both the untreated control plots and the "two-element" fertilizer plots. Here again the question whether the increases are profit-yielding still remains to be determined.

4. The kind of fertilizer used seems to have been without significance, one being just as good as another, subject to the limitations above noted.

5. The amount of fertilizer used seems likewise to have been without significance (subject to the same limitations).

6. Even when fertilizer experiments are properly planned and the results adequately studied by statistical methods, our present knowledge of the enormous variability of all soils and plants renders the data from any given fertilizer plot of value only on that plot, no matter how near the experimental one. This important consideration renders it highly probable that no fertilizer experiment as ordinarily conducted is possessed of sufficient practical value to justify the large expenditure of money, time, and energy involved.

We wish to emphasize that we are not desirous of making a fetish of the application of statistical study to fertilizer experiments. Nevertheless, we must say that if statistical methods, inadequate as they may be, should not prove applicable to an evaluation of the results of fertilizer experiments, the latter must be accounted of even less value and significance than we have here accorded to them.